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MANUFACTURING TECHNOLOGY PROJECT REPORT

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FINAL REPORT

POSITIVE ANODE MAGNETRON

George Boles
Microwave Associates
Burlington, Massachusetts

1 November 1980



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PREPARED FOR

MICROWAVE TECHNOLOGY OFFICE, Code 9203
NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

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FINAL REPORT
FOR
MANUFACTURING TECHNOLOGY PROGRAM
POSITIVE ANODE MAGNETRONS

PREPARED FOR
DEPARTMENT OF THE NAVY
NAVAL OCEANS SYSTEMS CENTER
SAN DIEGO, CALIFORNIA
PERIOD COVERED: 31 JULY 1977 - 15 OCTOBER 1979

PREPARED BY
GEORGE BOLES
SENIOR PROJECT ENGINEER

19 MAY 1980

APPROVED BY
DAVID HOBBS
BUSINESS CENTER MANAGER
MAGNETRONS/TRANSMITTERS

MICROWAVE ASSOCIATES, INC.
BURLINGTON, MASSACHUSETTS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes an effort to establish a cost-effective technology for positive-anode magnetrons used by the Navy. This technology was first applied to reduce the cost of tubes used in commercial weather and marine radar. Commercially available, standard, inexpensive parts and the results of analysis of part cost (tolerances) vs cost and complexity of fixturing provided the technology base. The tubes fabricated during this program were all sub-specification. Some tubes exhibited one or more problems such as excessive spurious output, low efficiency and low output power. The last four tubes made were free of spurious emissions but were low in output power.		

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20. ABSTRACT (cont)

This program demonstrated that there are techniques available to reduce the fabrication cost of tubes, but the program also showed that the changes could indirectly affect rf performance and could require tube design changes.

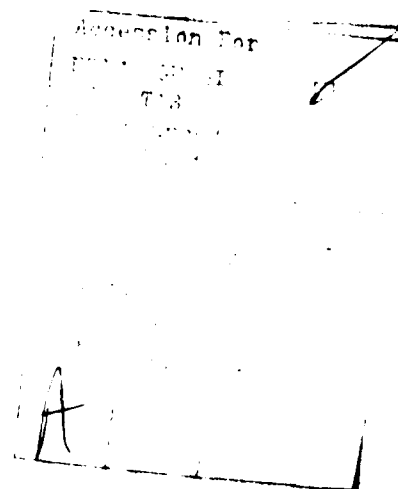
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1.1 OBJECTIVES OF PROGRAM

The purpose of this program was to establish improved or new processes and technologies for the manufacture of magnetron tubes for Navy missile fuzes. The technology includes positive anode magnetron techniques.

The program also includes demonstration of pilot production fabrication processes and techniques to realize lower manufacturing costs of about 30% through simplification of magnetron parts for manufacturing ease.

1.2 PROGRAM SUMMARY

1.2.1 This report covers the time period from August 1977 (inception of program) through 15 October 1979. The program was completed on the latter date.

1.2.2 Included is a discussion on the technical problems encountered and their impact on the program.

1.2.3 Due to the technical problems encountered the program was extended by nine months and the overall scope of the program reduced by mutual agreement.

1.2.4 Original funding was expended by May 1979. Microwave Associates, Inc. MA continued the effort on company funds to demonstrate the solution to the technical problems.

1.2.5 Four magnetrons were delivered to the Navy Department in October 1979.

1.2.6 This device demonstrates the capability of manufacturing a magnetron for this application at a cost savings of at least 30% over the present device.

2.0 PROGRAM TASKS & SUMMARY OF PROGRESS

This manufacturing technology program was originally divided into ten tasks, which can be summarized as follows:

- Phase 1
 - Design and Analysis
 - Task 1
 - Modification of existing tubes in order to establish a simplified design.
 - Task 2
 - Develop tooling techniques and processes for quantity production using the simplified magnetron layout.
 - Task 3
 - Establish tolerance limits such that performance requirements are met at lowest cost.
 - Task 4
 - Establish test procedure and test equipment which will provide adequate and sufficient tests at lowest cost.
 - Task 5
 - Demonstrate compatibility of the tube design with two Navy fuze systems.
 - Task 6
 - Fabricate productized tubes in sufficient quantities (five tubes) to determine that process controls can be maintained when adapted to new process production.
- Phase 2
 - Task 7
 - Describe new mechanical and electrical parameters in MIL-E-1 format specification.

- Task 8 - Prove out and report data on all fabrication, assembly, processing, and measuring steps and procedures required to produce the tubes.
- Task 9 - Document and report piece-part dimensions, and materials of all manufactured and purchased components.
- Task 10 - Initiate pilot run of 20 preproduction samples, and qualify tubes for system implementation.

The steps required for the completion of each task were spelled out in great detail in the overall program plan. This was presented in our original technical proposal.

Tasks 1 through 5 were completed on or slightly ahead of schedule. The technical section of this report discusses the progress. In task 6, which included brass-boards, debugging, and prototypes, we incurred a technical problem. As outlined in detail in section 3, this problem caused a major delay in program progress. Before this problem was solved, a restructuring of the program was necessary. Ultimately we requested, and obtained, a 9-month extension of the program, at no cost to the government, and a revision in scope. In return, MA funded the last 5 months of the program.

The revision in scope deleted Phase 2 (Tasks 7, 8, 9

and 10) in its entirety, including the preparation of manufacturing documentation, the construction of a pilot run of 20 tubes, and final qualification testing.

It was also agreed that only four deliverable units were required in Task 6, provided these units were built in a continuous manner.

A solution to the technical problem was accomplished by July 1979, and the final four units were built, tested, and delivered by 15 October 1979. Due to material delivery delays, fabrication of the fourth and final device was rushed to meet the scheduled completion date. This "rushed" mode precipitated a decision which resulted in this last unit having less than the required amount of output power. This was not unexpected and completed the restructured program.

Units delivered on this program were applicable to only one Navy fuze.

3.0 TECHNICAL DISCUSSION

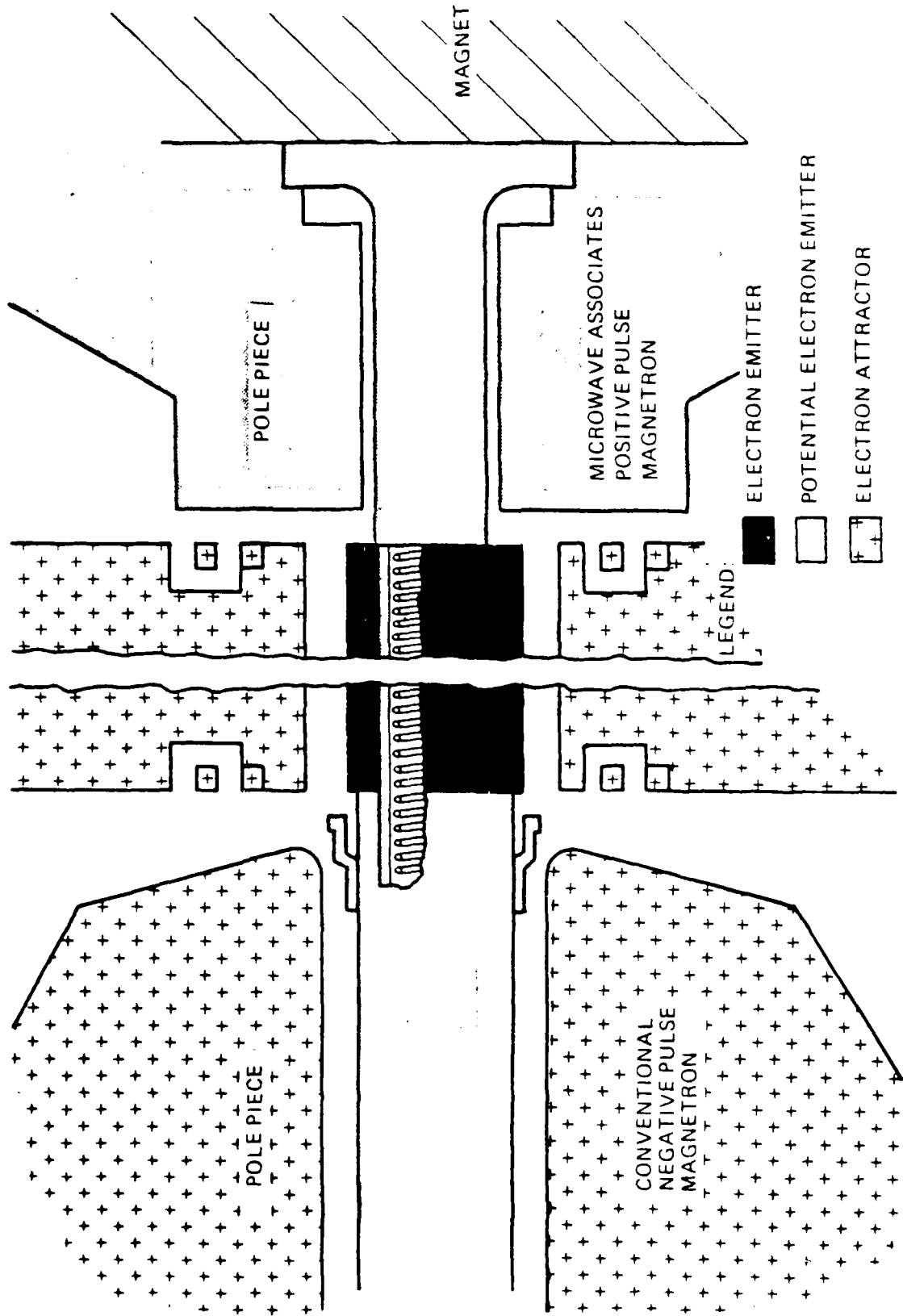
3.1 Introduction

This reviews the work completed under Navy Department Contract N00123-77-C-1018 encompassing manufacturing technology for the generation of positive anode magnetrons. We shall start with a brief description of the product and its generic family. We will discuss the antecedent technology program funded by MA which developed the requisite concepts and yielded a family of cost-effective, lightweight, compact, X-Band magnetrons for commercial weather and marine radar applications.

We will compare the configuration of this novel X-Band line with that of our standard military line. We shall present a layout of the proposed positive anode magnetron and compare it too with the existing X-Band line. We shall point out areas where commonality can be maintained for maximum cost effectiveness, and where it can not be maintained and the reasons for this.

3.2 Description of Positively Pulsed Magnetron

Figure 1 illustrates the essential difference between the conventional magnetron and the positively pulsed magnetron. With the conventional magnetron, the anode and pole pieces are electrically connected together and to ground, and a negative voltage pulse is applied to the cathode. The electrons would like to go to the pole



COMPARISON OF NEGATIVE-PULSE AND POSITIVE-PULSE MAGNETRONS

FIGURE 1



pieces and be wasted, but are limited from doing so by hot Faraday shields (commonly called end hats) suspended at either end of the cathode. There are many problems associated with these shields. They tend to become emissive themselves, resulting again in electron waste; they help cause arcing; and they result in geometric disturbances in the field shapes. The positively pulsed magnetron, on the other hand, eliminates these shields because the pole pieces are at cathode potential and operated at ground potential. A positive voltage pulse is applied to the anode. Without these shields the pole pieces can be designed to provide uniform magnetic fields, and there is little electric field disturbance. Spectral performance of this type of magnetron rivals that of practical coaxial magnetrons. Pulse jitter and moding are minimal.

Since 1960, MA has been looking at ideas for radical simplification of the positive-pulse magnetron. The prime objective of this concept was "cost effectiveness," with simplification, standardization and miniaturization as obvious secondary objectives.

In 1974, we made the decision to invest in a company-sponsored manufacturing technology program to develop an X-Band "cost effective" magnetron to satisfy the commercial weather and marine radar market.

Figure 2 shows the layout of a typical positively pulsed design. This concept is standard with our military line. As can be seen, it has fairly large pole pieces extending deep within the device and is surrounded by a large and heavy magnet.

Figure 3 is a cutaway drawing representing our X-Band cost-effective device resulting from the company-funded technology program. Note in this design we use very small pole pieces, with small bar magnets appearing to be inside the device. The concept allows us to use off-the-shelf low-priced magnet bar stock cut to length and placed near the interaction gap (which is the center and heart of the device), thereby increasing the magnet circuit efficiency and enabling a substantial size and cost reduction. The metallic enclosure in which the device is packaged becomes the magnet circuit return path. The metallic enclosure is further functional in that it prevents the radiation of spurious emissions and minimizes the requirement for costly and complex radio frequency interference shielding for close-proximity circuitry. This metallic enclosure, incidently, is an off-the-shelf inexpensive transformer can with a few holes punched in it.

The commercial cost-effective magnetron at X-Band is a successful embodiment of these concepts. Versions are built in production at 1 kW and 5 kW peak power output.

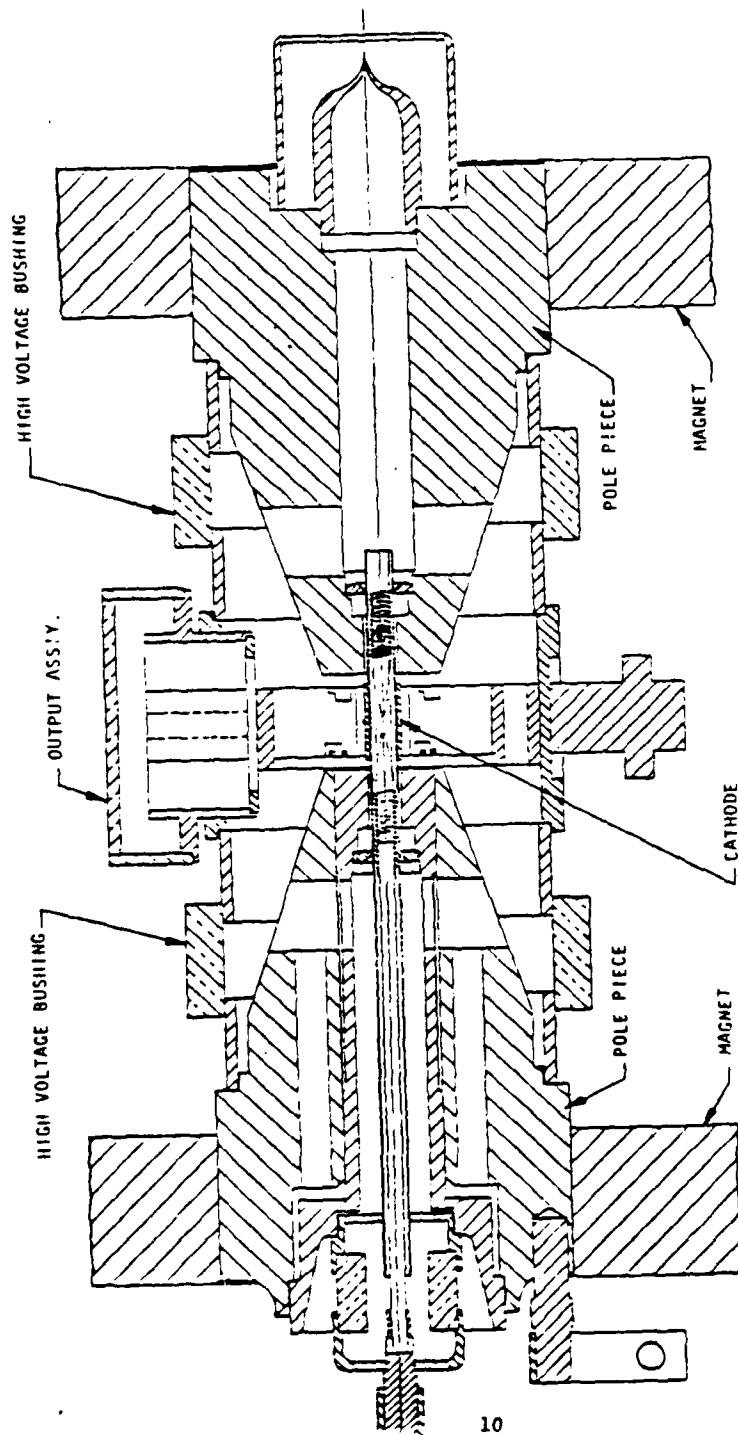
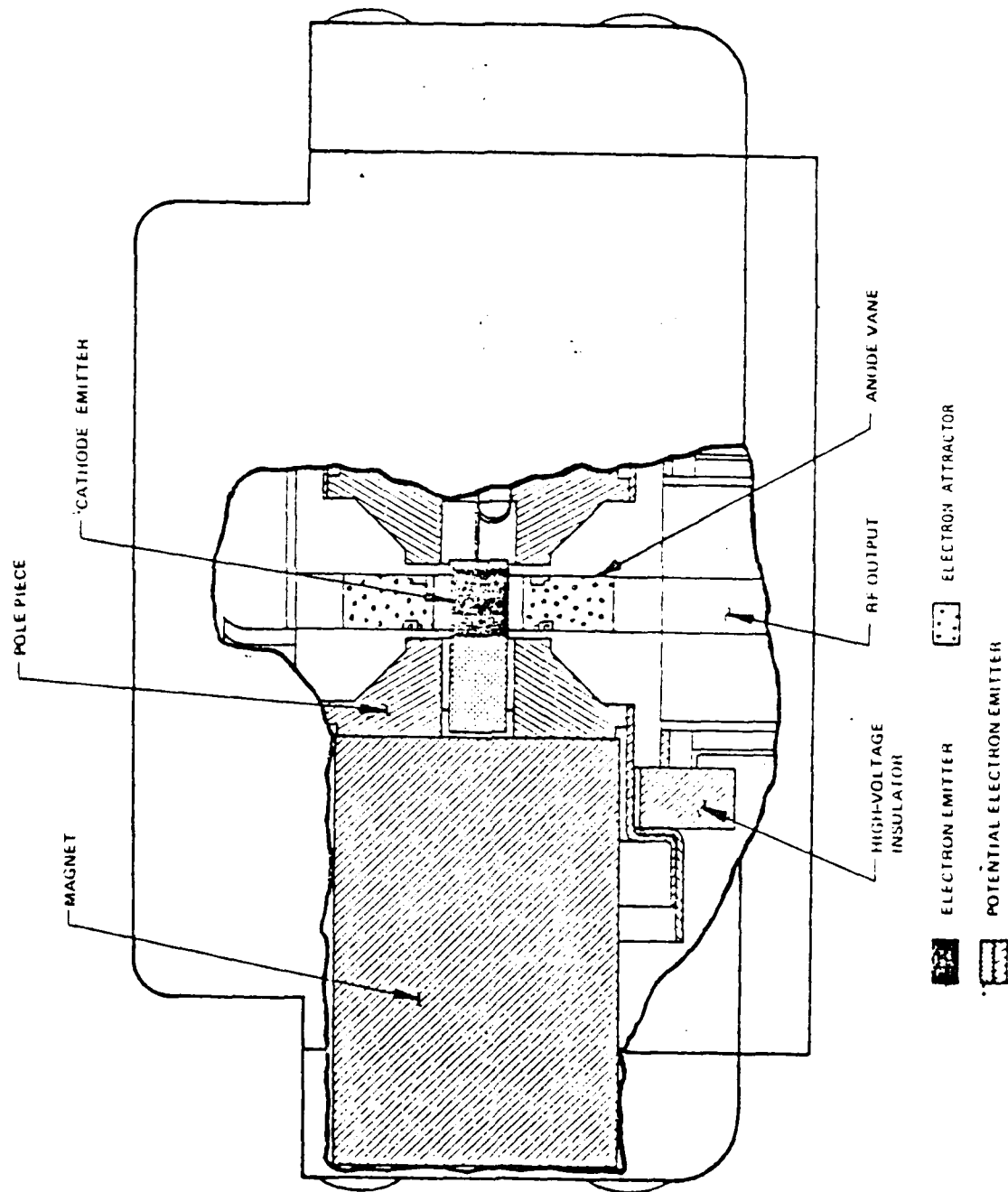


FIGURE 2 PRESENT MILITARY MAGNETRON



MICROWAVE ASSOCIATES LOW COST MAGNETRON

FIGURE 3 MICROWAVE ASSOCIATES LOW-COST MAGNETRON

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Figure 4 shows a cutaway layout of our present X-Band device and a layout for an early model of the militarized version of the device developed during this program. Although the device is not shown in a packaged configuration, the packaging concept, an off-the-shelf transformer can, remains identical.

Comparing the two devices, one immediately sees that the center area of the new device consists of smaller parts than that of the X-Band device, since the newer device operates at both a much higher frequency and much lower power level. Each of these parameters requires smaller shapes and sizes. Because of these constraints, the material in the anode and cathode circuitry requires different piece parts from our X-Band line. The technology developed from our X-Band program is maintained, however. The cantilevered cylindrical cathode structure maintains a diameter-to-height ratio approaching unity. This results in maximum strength and rigidity - very important in some military environments.

The technique of using very small pole pieces located deep within the device to allow for the use of small lightweight, bar stock magnets is maintained. In this case a slight grinding operation is required due to the stepped configuration of the cup surrounding the magnet. This modification of the X-Band design stems from the very low

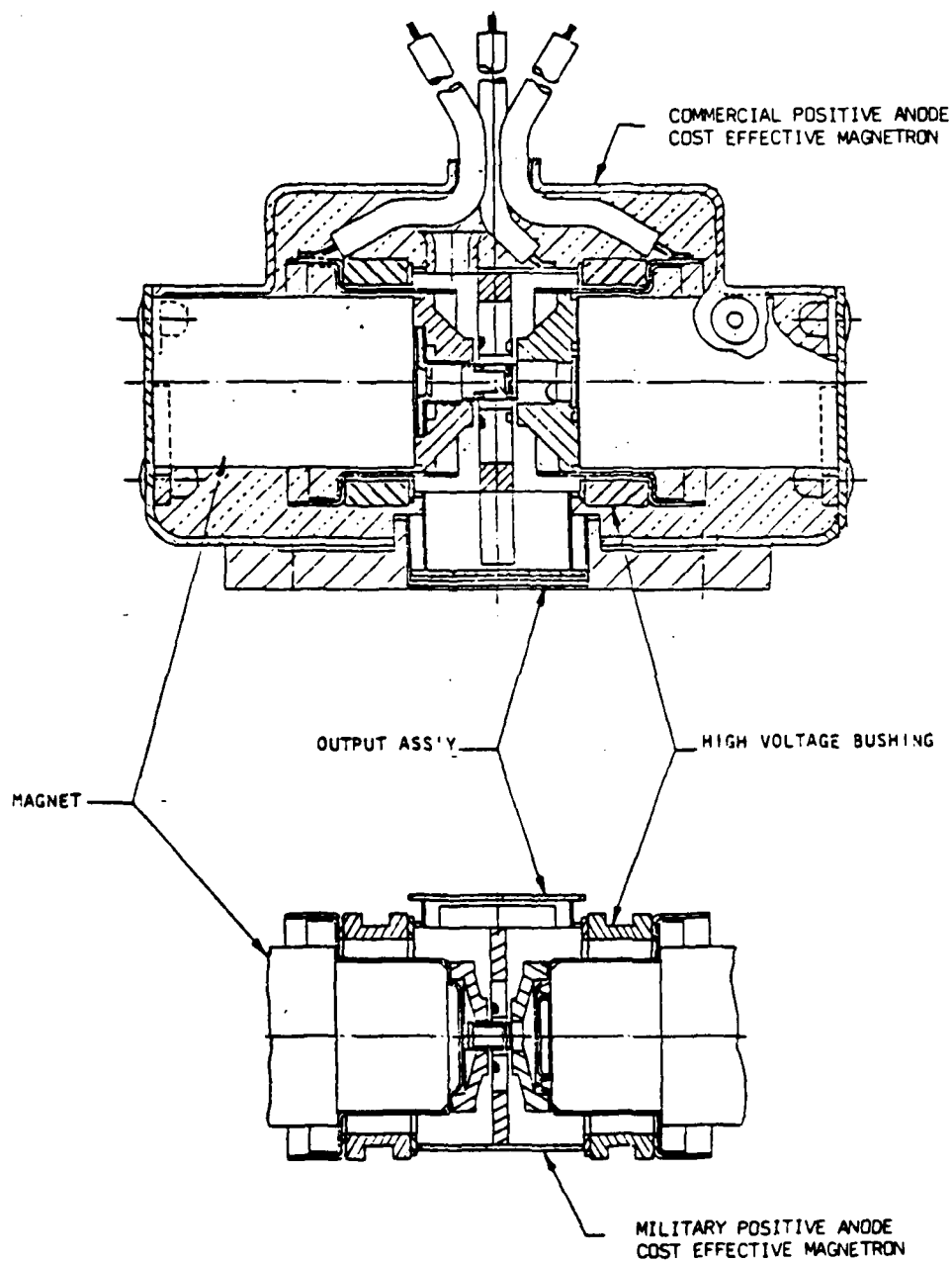


FIGURE 4 LAYOUTS OF TWO VERSIONS OF MA
POSITIVE ANODE MAGNETRON

input-capacitance requirement imposed upon the military device. The differences in the high-voltage bushings also result from this input-capacitance requirement.

3.3 Discussion of Performance of Contract - Task One

Task One was designed to analyze the present devices we now manufacture; their applications, reliabilities, and peculiarities. Discussions with system personnel, both civilian and military, took place to insure maximum effect from the program. Both proposed devices were analyzed against the concepts of our existing X-Band device. Techniques developed for the X-Band device were analyzed with regard to the military environments.

Examples of these techniques include, but are not limited to:

1. Use of "pop" type cold rivits in the packaging phases.
2. A cantilevered "oxide" type cathode with an extremely low height-to-width ratio.
3. Reduction in the use of precious and/or sophisticated metals (i.e., gold, silver, exotic nickel alloys, etc.)
4. One step "throw together" assembly procedures previously requiring many highly controlled steps.

Materials from all devices were mixed and/or modified to analyze the reconfigured circuits. Areas of

compatibility were identified and analyzed. Compatibility analysis consisted of decisions on commonality of material, processing specification, and processing techniques. Specifications for the two devices were analyzed and reports describing areas which could result in substantial savings, should some specification modification be allowed, were forwarded for review.

A layout for the first developmental model was then generated. The layout was devised to encompass devices for both applications, with only minor modification to allow for differences in power and frequency.

Task One of the program was successfully completed and within the allocated time and cost objectives.

3.4 Task Two

Task Two was designed for the developing of tooling techniques and the determination of processes for a production mode of operation.

Each of the proposed circuits was analyzed on an individual basis from a cost, yield, reliability, and work simplification standpoint. Each area was looked at from a value engineering point of view that analyzed the interaction between tooling, material, techniques, and operator skill level. The analysis was a judgmental trade-off between piece-part cost (tolerances) vs. cost and complexity of fixturing to net acceptable yields of acceptable quality. The underlying

philosophy was to make the heavy investment in the fixturing (a one-time investment) and purchase cheap (minimally toleranced) parts from then on. The tolerances on and the methods of the fixturing techniques would overcome the inconsistencies in the material, and net performance would be within an acceptable distribution curve. This approach must also be tempered by the need to maintain simplification in the fabrication process in order to minimize the labor skill level required and the impact of the "human factor." Then, at the end of this task, a complete objective review was undertaken, with modifications injected when and if deemed necessary.

Task Two of the program was successfully completed and within the allocated time and cost objectives.

3.5 Task Three

Using the information of the designs generated previously, we now assigned the piece-part tolerance limits. These limits are the minimum required to achieve the circuit objectives. This was done to minimize part cost, etc., as explained above.

As with our X-Band device, the use of commercially available inexpensive parts or material, whenever possible, was our prime objective. Examples of this are magnet bar stock, transformer cans for housing, pop rivets, etc.

Task Three was also successfully completed within the allocated time and cost objectives.

3.6 Task Four

The fourth task of this program was for the establishment of test procedures and a proposal for test equipment. The line items or steps of this task required the generation of a specification sheet (called TTS) and a written test flow plan for the new device using the format requirements of MIL-E-1.

Also required under this task was the analysis of processing and/or test equipment for the purpose of automating same. The objective here is to eliminate the human factor wherever possible.

The analysis consisted primarily of a cost-vs-return study. The investment recovery time for automating operations equivalent to those presently automated on the existing military programs was excessive and would be contrary to the objectives of the program. Of the considerations explored, it was hypothesized that integration with our present X-Band line with a sufficient combined annual volume would make some form of automation cost effective. At presently forecast levels however, the additional anticipated scrap produced by human error was the most economical mode of operation. This scrap factor supposition was based on history gleaned from our X-Band line.

After completion of this task, it was decided by the user agency that it was more desirable to retain the present NWC format specification.

3.7 Task Five

Under this task we demonstrated a compatibility between the existing military systems for which the devices are proposed.

The device as originally proposed had flying leads instead of solder terminals. This concept was accepted by the Navy Department by virtue of acceptance of, and reference to, our original proposal in the contract. This task also required the generation of an additional MIL-E-1 TSS for the second device.

Drafts of the proposed MIL-formatted specifications were generated as required for both the primary and secondary devices. These specifications were forwarded to the appropriate stations. The drafts were a result of analyzing both mechanical and electrical requirements imposed upon the devices. These requirements included those imposed by existing specifications as well as those gleaned from liaison with Navy Department personnel (i.e., China Lake) and systems manufacturers.

Under Task 5, the generation of a composite specification, the final product as originally required, was not accomplished due to redirection from the Navy Department.

The combined Compatibility Conference and Mid-point Review (as directed by contract) was held at NOSC in February 1978 as scheduled. The program at that time was slightly ahead of schedule, on budget, with no major problems.

3.8 Task 6

Under the requirements of Task 6, initial procurement of brassboard material was undertaken. Material was purchased using procurement specifications generated earlier in the program. This material was subsequently processed using processing specifications also generated earlier. All procurement and processing steps were reanalyzed by the engineering staff during execution and were found to function and exercise all proper controls as planned for.

Initial brassboard work began with the fabrication of major and minor subassemblies. The actual fabrication was done by technician-level personnel under engineering supervision. Close attention was given to the ease and simplicity of fabrication and the accuracy of the results in order to insure that objectives in these areas were being realized.

Fixturing designed to control broadly toleranced parts functioned as expected, producing mechanically correct subassemblies. Resonator frequencies were within the calculated limits as were "Q" levels. Operating temperature of the cathode subassembly was correct and within the limits of the input power requirements of the NWC specification.

The integral ferrite circulator went together flawlessly, tuned in with ease, and tested well within the required limits.

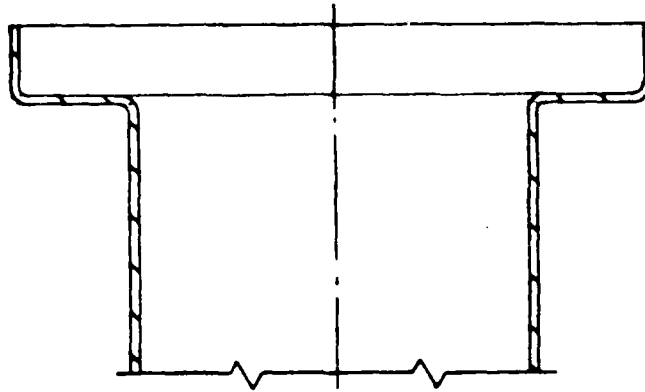
Most subassemblies integrated correctly, interfaced, and performed as designed. Designed accuracies, stability, and repeatability were achieved.

One of the major subassemblies to be used in one of the initial brassboards developed an unanticipated structural failure during subsequent processing steps. The failure resulted from the separation of two parts due to fracturing of an impulse-bonding weld.

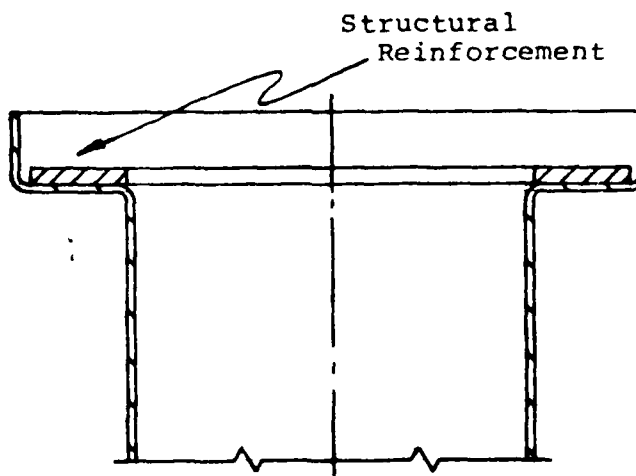
Due to the reliability requirement of the end product, it was decided that rather than attempt to control the process, the method of fabrication should be changed. The impulse-bonding technique was replaced with one of controlled-atmosphere brazing. By the nature of this procedure, the joint between the two members is at least as strong as the members themselves.

Additional structural reinforcement was required on the subassemblies used to support the magnets on the finished device. This additional support was designed to eliminate the possibility any structural shifting (i.e., oil canning) during severe environmental stress conditions (shock, vibration, etc.) See Figure 5.

During March and April 1978 the initial brassboards were fabricated and tested. Initial testing of the first devices disclosed severe coupling of the adjacent modes within the device. "Adjacent modes," (defined as the $\left(\frac{N}{2}\right) \pm n$ modes), exist in all magnetrons. They are typically inefficient,



Original



Modified

FIGURE 5 STRUCTURAL REINFORCEMENT OF MAGNET
SUPPORT SUBASSEMBLY

superfluous modes of operation, sometimes identified as spurious outputs, at some frequency well removed from the objective frequency and are not uncommon problems in magnetron development. This unwanted condition can usually be suppressed by quite common techniques. Some examples of these techniques are:

- 1) Increasing the designed resonator-mode separation.
- 2) Adjusting the $\left(\frac{N}{2}\right) \pm n$ coupling so tightly that oscillations cannot be sustained.
- 3) Adjusting the coupling so loosely that power transfer in this mode is of no consequence.

Because of the availability of these suppression techniques, it was felt that no immediate concern was warranted.

Testing, analyzing, and modifying continued through May 1978, but with no positive results in eliminating the adjacent-mode instabilities. The difficulty was not alleviated by either standard (state-of-the-art) solutions or major design changes.

Since it was possible that we would not completely understand this situation within the allotted "Debug Process" (Step 4, Task 6) time period, the Navy Department Project Engineer was notified. This notification generated an impromptu review meeting concerning the program and the problem.

The meeting, chaired by the Navy Project Engineer, took place at the MA facility in May 1978. It was decided during this meeting that the "Debug Process" could continue through June 1978 without impacting the overall program.

The following is a brief description of programs used to identify and analyze the problem during May and June of 1978. Computer-aided design options were generated for most changes to allow optimizing the desired conditions.

3.8.1 We modified resonator material and dimensions. To reduce program time, the brassboard work was done using material available in house, reworked and re-dimensioned while awaiting procurement of material as designed for this job.

3.8.2 A change in the strapping capacitance as a percentage of that of the resonator was made to increase the pi-mode-to-adjacent-mode separation ratio from normally acceptable design limits to one of extreme conservatism.

3.8.3 An increase in cathode diameter (a well-established method for improving stability), was tried.

3.8.4 Changes in the magnet pole configuration were empirically evaluated using "hot" and "cold" test methods.

3.8.5 Positive-pulse magnetrons commonly exhibit "hot package" problems due to rf radiation out the high-voltage

bushings. This was fully evaluated by rf probing and the use of absorbent material. Neither led to any positive conclusions.

3.8.6 Due to insufficient performance history on the unique output section we proposed to use on this device, we fabricated devices using a conventional ridged circular W/G output section to insure there were no contributing factors in this area.

3.8.7 Finally, a direct substitution of resonator, cathode, and output circuitry was made using those of present production magnetrons of similar frequency and power level.

None of these "fixes" cured the basic problem of moding which we had in this device. During this experimental phase a total of 15 brassboards were fabricated and tested in an attempt to understand and rectify the problem. This was many more than originally planned for the program. We consumed material at a much faster rate than planned.

3.9 Initial Redesign of Magnetron Structure

Due to the difficulty of solving this adjacent mode problem, we decided to do some major revisions of tube design. It was hypothesized that the problem was being caused by improper coupling of the proper mode (π) into the tube housing. We decided to attempt to fabricate both internal rf chokes and external rf absorbers to prevent energy from interacting through the high-voltage bushings. The chokes and absorbers were tried separately and together.

Cold-test analysis showed them to be working properly, but during hot test the problem persisted.

With coupling still the apparent problem, a major redesign of the output section was undertaken. As depicted in earlier reports, the slot in the anode block was configured to be the quarter-wave impedance matching network (i.e., matching low cavity impedance to higher waveguide impedance). This is different from the more conventional procedures but offered the advantages of eliminating relatively expensive transformer parts and allowing us to use many of the parts presently used on our X-Band commercial line. A possible disadvantage of this design could be end space coupling of energy. Because of the persistency of the moding problem, we decided to design an inexpensive shield, consisting of a bisected conical section, to cover the transformer portion of the block. Figures 6 and 7 show top and side views, respectively of the original and the new designs incorporating the conical shield.

The magnetic flux focusing pole pieces were also reconfigured to make room for the new (shield) output design. The pole reconfiguration is also shown in Figure 7.

Considerable time went into the cold-test work, which always requires some cut-and-try adjustments. The initial magnetron body fabricated to this design tested satisfactorily at cold test but was not as tightly coupled as desired. It was decided to proceed with the under-coupled device to prove out the modification.

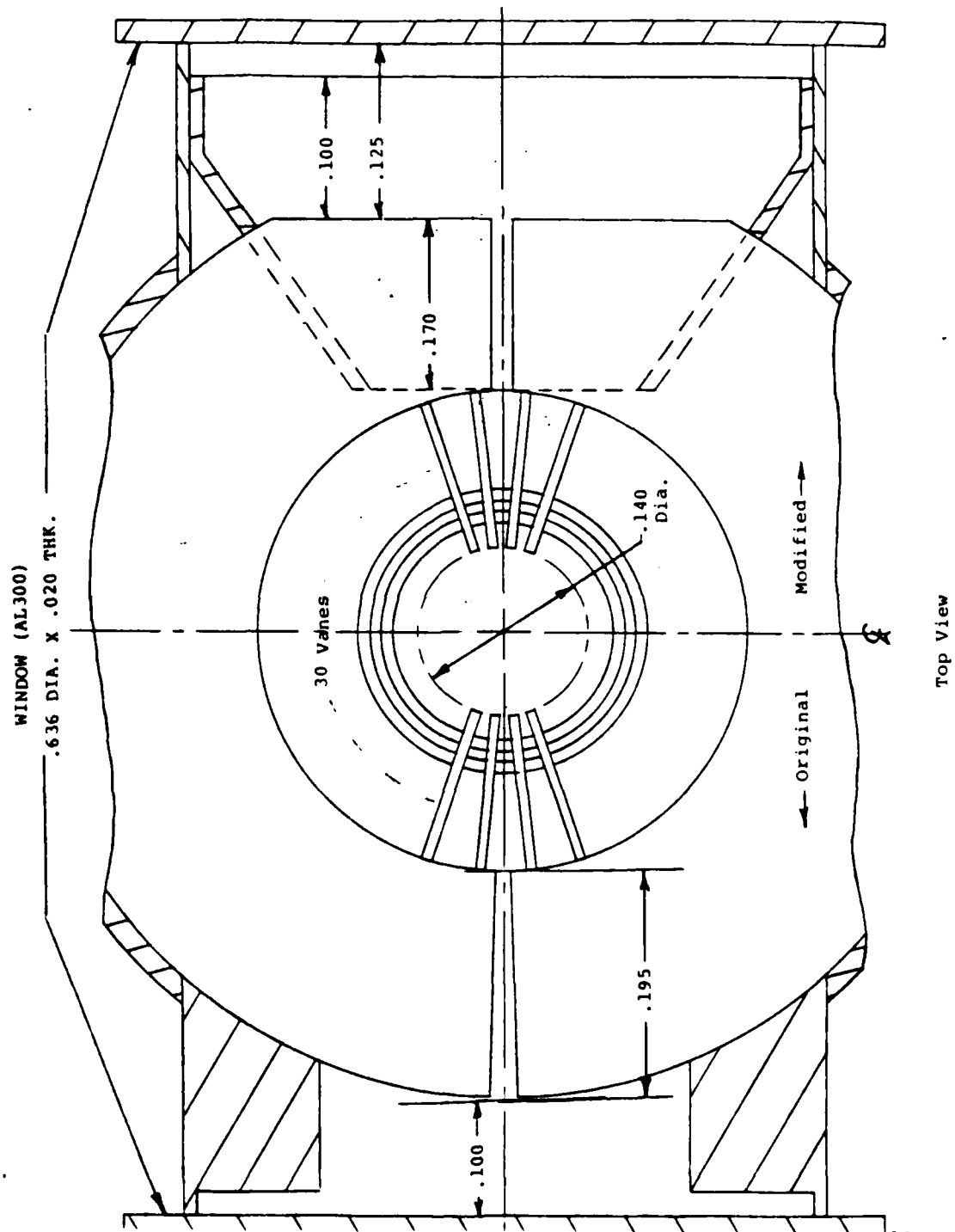


FIGURE 6 REVISED OUTPUT STRUCTURE, TOP VIEW

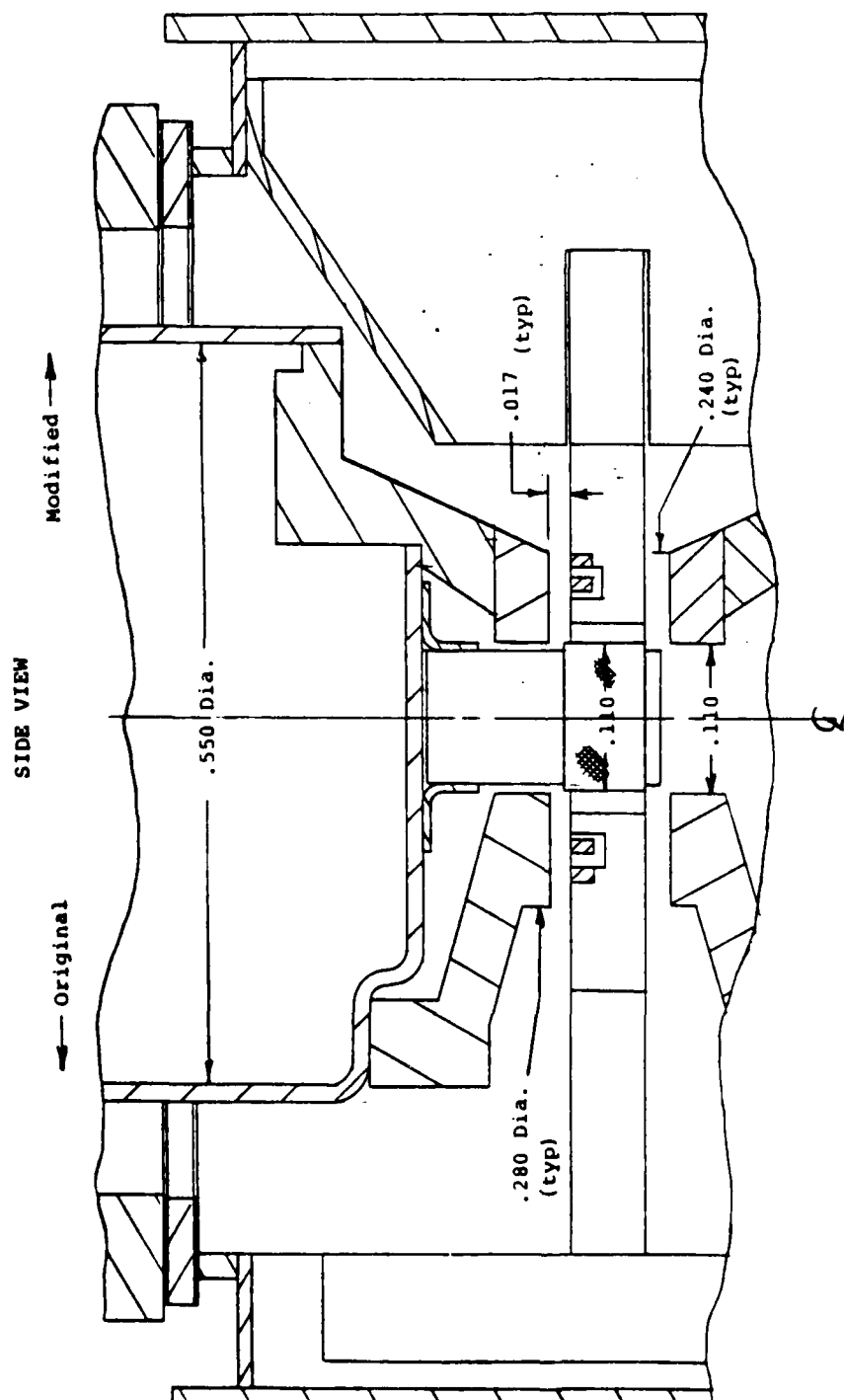


FIGURE 7 REVISED OUTPUT STRUCTURE, SIDE VIEW

The completed magnetron operated in the proper (pi) mode well beyond the drive range required with no evidence of the original problem. The device's not being as tightly coupled as desired resulted in a reduction in total efficiency (η) and a yield of only about 70% of the specified minimum power. This was as expected and further showed that the device was operating correctly.

At this point it was decided to move into the prototype stage. The time was September 1978, and the program was essentially still on schedule.

3.10 Prototype Phase

The prototype phase began with procurement of material to cover the reconfigured output section. The initial prototype was lost due to loss of vacuum integrity. The second prototype was a successful unit, with more than sufficient power, and met full performance requirements.

Extensive testing of the unit was done. All requirements of the Navy Weapons Specification were met, and additional characterization testing was undertaken.

Subsequent prototypes, however, were not successful. In addition to a recurrence of the original problem, which was never completely understood, many nonrelated problems were encountered, such as poor controlled atmosphere brazing joints and loss of vacuum due to ceramic-to-metal seal fractures.

The reappearance of the original adjacent-mode

problem along with the nontechnical problems caused considerable loss of time and material. A review of the situation with the Navy Project Engineer held in December 1978 generated the following courses of action:

3.10.1 Analyze nontechnical problems.

3.10.2 Provide logical tests to eliminate same.

3.10.3 Reexamine the entire tube design and reanalyze the output section.

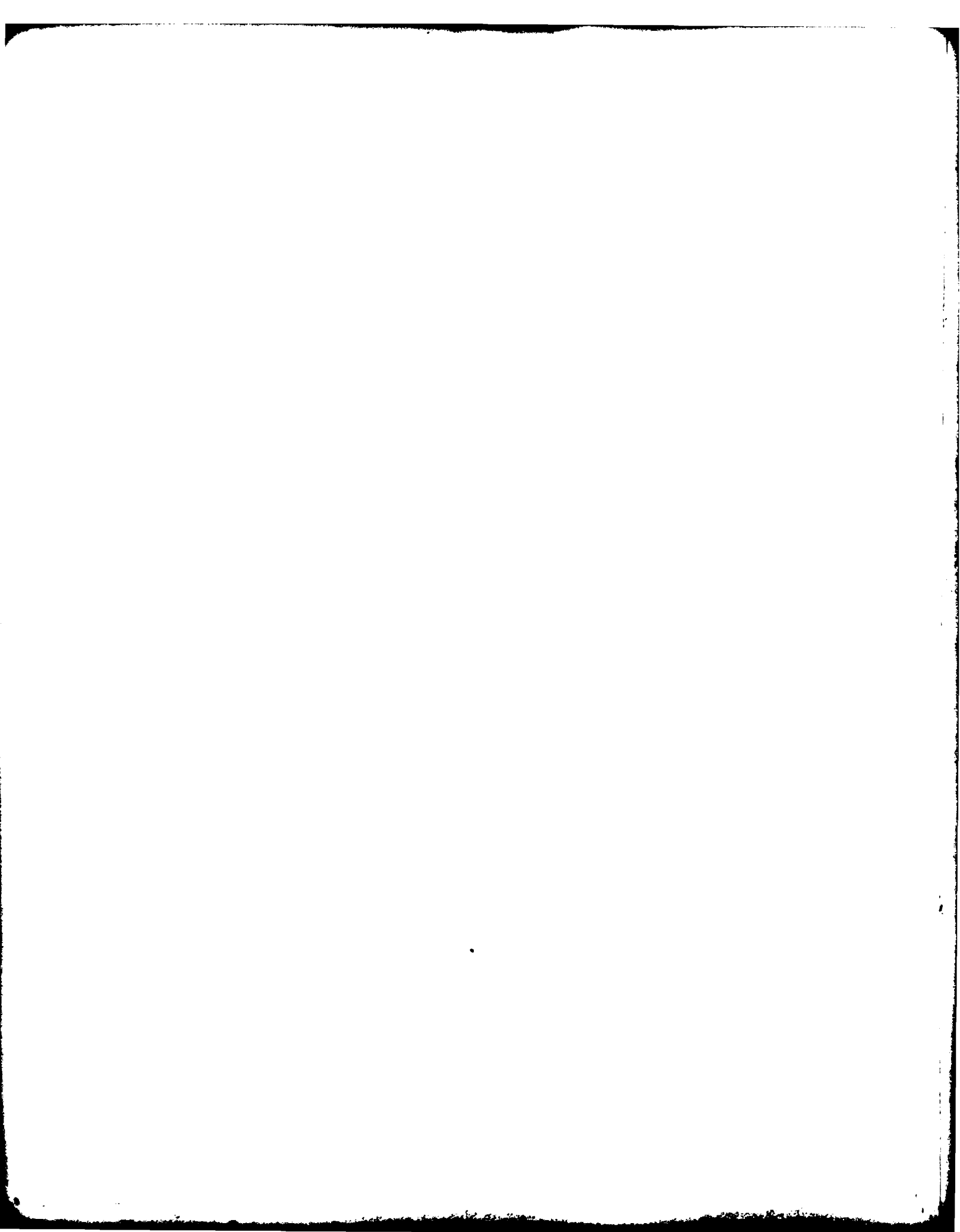
3.10.4 Build tube starts when all nontechnical problems were understood and corrected.

With the control of the nontechnical problems in effect, we undertook to refine our basic design, including the output section.

3.11 Second Redesign

With inputs from two outside experts and an indepth review of waveguide technology, we undertook several programs. The review of waveguide technology was to insure that no theory violations were being introduced. There were none. Fringe effects and interactions, which are intangibles, were excluded from consideration.

"Causes and effects" in the following experiments are difficult to extract. The basic problem with the device manifests itself at very low current levels (i.e., less than 30% of the operating point). At this level, oscillatory conditions are just starting. This makes the results of the experiments ambiguous in all respects except one: they did not prevent (or cure) the problem.



This covered the period from late December 1978 through April 1979.

3.11.1 The output window was redesigned to have bandpass characteristics similar to those used on the production family of magnetrons. The new window was designed with a reduced diameter. This diameter placed the window below cutoff frequency for all W/G modes except the desired dominant TE_{11} mode.

3.11.2 Special processing of the devices to simulate that used on one of our successful X-Band devices was undertaken. This process consisted of rapid cathode conversion with slow activation. The slow activation consisted of sustained rf aging below an apparent mode window, then a slow increase of peak current levels through this window. Once through this mode window, the higher operating peak currents could be reached without evidence of instability (moding).

There appeared to be some initial improvement in units fabricated for this program; but the improvement was not sustained in subsequent operations.

3.11.3 The use of special cathode emitting materials with unique base metal preprocessing to minimize possible cathode interface resistance was attempted. This unique process, called decarbonizing, consists of burning off carbon and other occluded trace elements. The intent is to minimize the I^2R losses due to the base metal/emitting material interface resistance.

3.11.4 Magnetic field experiments were performed. The small integral magnets were replaced with large electromagnets. These electromagnets allow the experimenter to vary the strength as well as the direction of the H-fields. Magnetron performance is a first-order function of these fields. The fields were varied from a zero level to a level above cutoff. The field direction was reversed, focused off center and skewed (unbalanced). No changes in the problem were perceived other than those predictable by H-field calculations.

3.11.5 Length variation in the output section was tried. The length was varied over a full quarter of a guided wavelength with no effect on the problem.

3.11.6 End space fillers were designed and tried. These drastically change "end cavity" resonant frequencies. The problem did not change and was determined not to be caused by end cavity resonance.

3.11.7 Investigations into longitudinal parasitic oscillations were made. Gold plating the pole tips to suppress secondary electron emission was tried. Again test results showed that this experiment had no effect on the problem.

3.11.8 Major increases (to 0.114 in.) and decreases (to 0.106 in.) in cathode diameters were tried with no effect. These were tried independently and in conjunction with reductions in cathode height (down to 0.030 in.).

3.11.9 Prototype #2, the tube that performed well, was dissected after extensive x-raying to determine if anything was overlooked. A slight reduction in the output height, under

that specified, was discovered, and additional units were fabricated with this difference.

A series of injection locking experiments were performed. Tubes could be locked on frequency and in the proper mode only by injecting large amounts (approximately 500 W) of power. Through these experiments it was determined that the tubes were oscillating in the adjacent mode above the "moding" current level. Power generated from this adjacent-mode oscillation was radiating through the high-voltage bushings and not the output section. The output section in this case appeared to be operating as a reactive low-pass filter. This was a very unique situation and a very significant find. This caused us to again reanalyze the entire rf section of our design.

With the program now falling behind schedule and funding running ahead of results, MA requested of the Contracting Office, with cognizance of the Navy Project Engineer, a 9-month extension of the contract at no cost to the government. This extension has been granted under Mod # P00003.

Using the assistance of our in-house technical experts and a theoretical analysis of the rf section, it was hypothesized that the varying impedance of the output section might contain a large reactive component. The impedance along this section should, in theory, be purely resistive. The hypothesized reactive component would make the device extremely sensitive to load coefficients and phasing. It would also

make the device sensitive to tolerance variations in its internal geometry.

To test this theory, an output section of constant impedance was designed. Maintaining the bisected cone configuration to prevent end space coupling, a tapered "T" section was introduced along the output slot. Figures 8 and 9 depict this new configuration. The length of the section was increased to agree with the now lengthened one-quarter wavelength guide, which this section should be.

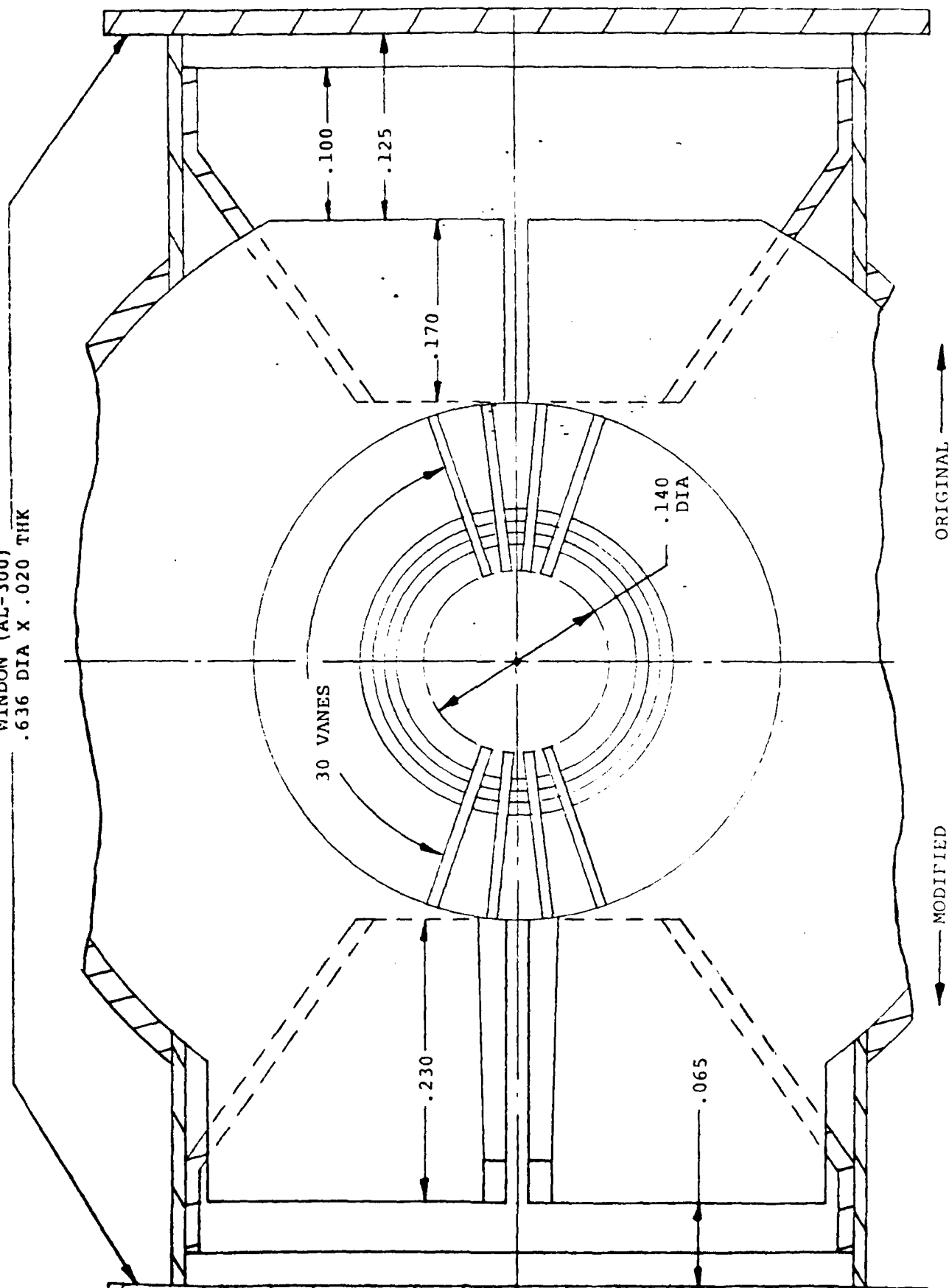
This is a computer-aided design, with the "T" sections varying in cross-sectional area as the cross-sectional diameter of the cone varies. This should maintain a constant nonreactive impedance along the full length of the output section (i.e., from cavity back wall to ceramic window).

3.12 Construction and Testing of Final Units

During July through October 1979, we built five additional prototype magnetrons using the new output structure. These tubes were carefully built and cold tested at each step of the process. The new output exhibited a somewhat lower coupling than we desired, and minor modifications were made in some assemblies to help alleviate this.

The final device fabricated was delayed due to material delivery problems. In order to have the unit finished for the scheduled review by the Navy Project Engineer, a

WINDOW (AL-300)
.636 DIA X .020 THK



ORIGINAL →

TOP VIEW

→ MODIFIED

FIGURE 8 SECOND REDESIGN OF OUTPUT STRUCTURE, TOP VIEW

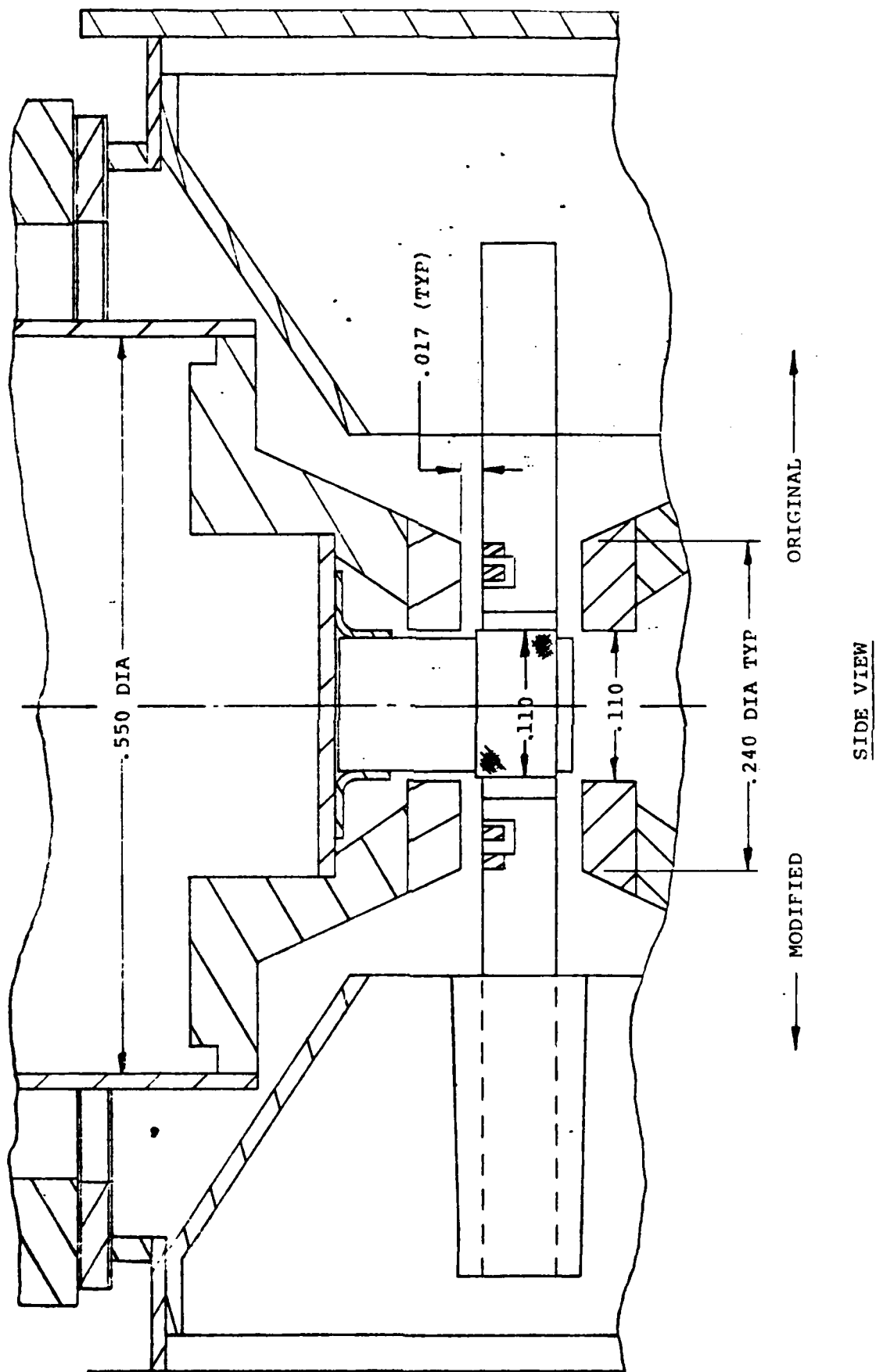


FIGURE 9 SECOND REDESIGN OF OUTPUT STRUCTURE, SIDE VIEW 35

decision was made not to make the minor adjustments to the coupling and to proceed with an under-coupled device.

It was further hypothesized that if the problem had been correctly identified and corrected, then this output section with a low η_c (circuit efficiency-coupling factor) would still present a nonreactive component of proper pass-band characteristics to the resonators, and the magnetron would perform correctly but be low in output power. This was found exactly to be the case.

Four of these tubes were exhausted (the fifth developed a leak in a seal). All tubes oscillated properly at the pi-mode frequency with no signs of any tendency to mode. Stability was excellent on these tubes.

Complete data were taken on these magnetrons. These data are included in Section 4 of this report.

3.13 Conclusions

The technical problem encountered in this program has been resolved and magnetrons subsequently fabricated operate properly. Some "fine tuning" will be required in the output section to increase the η_c to insure a margin of safety in output power.

Some further work will be needed to reduce rf radiation on the flying leads should this be a system problem. Absorbent material is presently being used in our X-Band line for this purpose. Although some of the same material was used for this program, it was not adequate to do the job. The higher frequency of the devices will probably require a con-

figuration change in the absorber, or possibly a different absorber.

This manufacturing technology program has shown the feasibility of applying the philosophy and design concepts of our commercial cost-effective magnetrons to military devices. These concepts have been applied successfully to positive anode magnetrons in this program, but can be profitably used for cost reduction on conventional magnetrons also.

4.0 DATA ON TUBES SHIPPED

MA2839 DATA SHEET

PARAMETER	UNITS	LIMITS		TUBE #'S			
		MIN.	MAX.	10278	10483	10484	11186
HEATER CURRENT	ADC	0.75	0.87	.804	.836	.863	.855
PULSE STABILITY	MP'S%	-	0.1%	.00	.00	.00	.00
PAV	KV	1.6	1.8	1.8	1.8	1.8	1.8
PO	W	650	1000	610	620	610	420
OCS FREQ	MHZ	250	350	374	354	335	316
HEATER SENS	DB	-	1.0	0.22	0.01	0.15	.10
PULL	MHZ	-	5.0	1.2	1.4	1.7	1.5
PUSH	MHZ/A	-	10	1.66	1.43	1.66	0.60
BANDWIDTH	MHZ	-	$\frac{2.5}{\text{TPC}}$ (2.5MHZ)	1.2	1.2	1.2	1.2
SLR	-DB	8	14	10.0	12.0	11.0	10.0
THRESH OSC	MA	5	20	19.0	35.0	50.0	23.0
RF RADIATION	DBM	-	0DBM <u>*NOTE</u>	240MV	400MV	370MV	250
BODY CONTINUITY	Ω	-	0.1	.039	.0385	.018	.030
INPUT CAPACITANCE	PF	17	23	24.8	23.6	24.7	23.7

*38MV = 1MW = 0DBM (SEE CAL SHEET FOR P.P. 260) MOST LEAKAGE APPEARS AROUND H.K. LEAD,
AND WIRE SUPPORT EPOXY

PARAMETERS	UNITS	COND	LIMITS		TUBE #'S			
			MIN	MAX	10278	10483	10484	11186
LOW BAROMETRIC PRES	CORONA		-	-	NO CORONA	NO CORONA	NO CORONA	NONE
WEIGHT	OZS.			20	12.85	12.53	12.46	-
TEMP COEFFICIENT	KHZ/°C		-50	-200				
		1			-200	-111	-155	-
		2			-200	-225	-225	-
		3			-300	-225	-150	-
		4			-300	-175	-300	-

PDA VIBRATION

THERMAL SHOCK

TEMP EXTREMES

MECHANICAL DATA SHEET MA2839

LTR DIMENSIONS S/N S/N S/N S/N S/N

BASIC

INCHES (MM) INCHES (MM) INCHES (MM)

QUALITY CONFORMANCE INSPECTION, PART 1

D

A 1.500 38.10 1.500 1.501 1.507
 B .276 6.91 .275 .276 .275
 C .956 24.28 .952 .951 .952
 D .497 12.62 .496 .497 .497
 E .994 25.25 .991 .990 .992
 P ✓ ✓ ✓

HELICOIL INSERT (#6-32 UNC - 28)
 MS-122118

R .187 4.75 ✓
 M .125 3.18 .126 3.20 ✓
 N .100 2.54 ✓
 U 1.850 46.99 1.870 47.50
 V .312 7.92 .372 9.45
 X .500 12.70 ✓
 Y 1.000 25.4 ✓
 Z 1.001 .999

40

#8-32 UNC-2A

QUALITY CONFORMANCE INSPECTION, PART 2

E

F 1.020 25.91 .994 .993 .991
 G 1.020 25.91 .996 .995 .997
 H 1.270 32.26 1.244 1.245 1.249
 J 1.270 32.26 1.258 1.247 1.241
 K .395 10.03 .375 .372 .374
 L 1.895 48.13 1.731 1.730 1.730
 AA .600 15.24 .590 .590 .590
 AB 6.0 152.40 10.5 10.5 10.5

NOT DONE

5.0 RECOMMENDATIONS

5.1 The solution of the problem which delayed the program and the shipment of the four prototype units has demonstrated that this concept for reducing magnetron manufacturing cost can be extended to military applications. We recommend that the Navy proceed with hardware development for suitable magnetrons.

5.2 The problem has revealed a basic area of weakness in positive anode magnetron design. We recommend that a study program be funded to provide a firm design protocol for output structures for isolated-anode magnetrons.

DATE
FILMED
-8